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AAMRL-TR-86-008

SUPERFICIAL TEMPORAL ARTERY MONITOR

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TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-86-008

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

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Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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This effort for the development of a concept demonstration superficial temporal artery pulse detector is a subset of a workunit devoted to the development of an artificial intelligence system combined with unobtrusive sensors for the purpose of the detection of acceleration induced loss of consciousness in fighter aircraft pilots. A non-invasive monitor was developed, evaluated and demonstrated. The experimental model operates at a frequency of 2.45 GHz with a power output of less than 40mW and an average power density not exceeding 2mW/cm^2 at the surface of the monitor. It is contained within a 64 x 64 x 20 mm thick polytetrafluorethylene housing covered on all sides by a thin metal casing for shielding purposes. A novel motion sensing circuit was employed in which miniscule current changes are produced in the bipolar transistor oscillator by fluctuations in antenna loading caused by the motion of the superficial temporal artery. Waveforms observed while the monitor is held securely against the head proximate to the superficial temporal artery clearly show pulse action.

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PREFACE

The work reported in this document was performed under the mission of the Armstrong Aerospace Medical Research Laboratory (AAMRL) workunit 7231-35-01 (Biotechnology-Tactical Air Combat) as a sub-contract task assignment to the RCA Laboratories, Princeton, NJ via the Engineering Support Services Contract No. F33615-81-C-0500, Systems Research Laboratory, Dayton, OH.

This effort for the development of a concept demonstration superficial temporal artery pulse detector is a subset of the workunit effort devoted to the development of a pilot loss of consciousness monitor system. Funding for this effort was provided by FY85 Laboratory Director's Discretionary Funds.

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FIGURE LEGEND

SUMMARY

The purpose of this final report is to document the effort and results of a program to provide a non-invasive device to detect the superficial temporal artery pulse in human subjects exposed to high onset rate, high sustained +Gz acceleration stress. Work was performed in general accordance with a task statement provided by the Systems Research Laboratories and an earlier proposal submitted by RCA Laboratories. Copies of these statements are included in this report for reference.

Based on the results of previous work on similar devices, a non-invasive monitor was developed, evaluated briefly, demonstrated, and delivered for further evaluation. This experimental model operates at a frequency of 2.45 GHz with an output power of less than 40 mW and an average power density not exceeding 2 mW/cm^2 at the surface of the monitor. It is contained within a 64 x 64 x 20 mm thick polytetrafluorethylene housing covered on all sides other than the antenna face by a thin metal case for shielding purposes.

A novel mixer-less motion sensing circuit was employed in which miniscule current changes are produced in the bipolar transistor oscillator by fluctuations in antenna loading caused by the motion of the superficial temporal artery. This current change produces a small voltage variation which is amplified to approximately 100 mV and brought out on a signal cable for observation on an oscilloscope or a chart recorder.

Waveforms observed while the monitor is held securely against the head proximate to the superficial temporal artery clearly show pulse action. Variations in the waveform are substantial as the position is changed, but the existence and timing of the pulse is distinctly evident in most positions where the several branches of the artery are located. Extraneous motions associated with muscle activity from speaking, chewing, or scalp flexing produce large,

overriding signals. External motions, especially to the immediate sides of the monitor, also produce extraneous signals because of microwave leakage from the airgaps between the flat antenna face and natural curvature of the subject's head.

A description of the monitor circuit and packaging is included in this report along with a more detailed review of the evaluation. A discussion of the limitations of the monitor and problems observed during the evaluation is also included with suggestions for improvements and other applications of this basic approach to physiological monitoring with microwaves.

DESIGN APPROACH

The basis of the non-invasive monitoring device provided under this program is the motion detection capability of simple microwave radar-like circuits in which phase displacements between transmitted and reflected signals can be related to physical movements of the reflecting surface. To monitor the pulsating motion of the superficial temporal artery or any other artery or organ of the human body with a radio signal, it is necessary to sense either (1) the phase-varying reflections from the body surface caused by the underlying organ action or (2) to directly monitor this action by causing most of the radio signal to penetrate the skin, fat or muscle tissue which overlies the artery or organ of interest. Microwave frequency radio signals are most appropriate for use since the physical displacements of the arteries and organs, although quite small, are significant in relation to the short wavelengths of microwave signals which are generally in the order of centimeters in air and further reduced in tissue by the dielectric properties thereof.

In the first instance, where the microwave reflections from the body surface are used directly, the reflected signals are usually substantial, although the portion attributable to the particular motion of interest may be small, and

easily detected at any microwave frequency. Higher frequencies are more suitable for surface monitoring because the shorter wavelengths can be better concentrated and have a greater phase difference sensitivity. For example, a 24.5 GHz signal with a 1.2 cm wavelength will develop a two-way phase difference of 6^{o} from a superficial artery movement of 0.1-mm.[1] At the lower frequency of 2.45 GHz, the phase difference would be only 0.6^{o} and difficult to detect. Respiration, which produces a substantial chest wall motion as well as an overall pervasive bodily motion, is readily observed by monitoring surface reflections. Superficial arterial action can also be detected from surface motion where the blood vessel visibly bulges, as in the case of a particularly gaunt individual, or when the skin is stretched tautly (such as when the wrist is bent outward to expose the radial artery). The major limitation to surface monitoring is that a slack skin covering of the artery will not transduce the arterial action into a surface motion. Other disadvantages of the surface monitoring technique are the greater tendency for external motions to interfere with the pulse waveforms, since the microwave signal can reflect obliquely from the head bouncing freely among other moving objects, and the considerable relative motion that may exist between the microwave unit and the subject which can generate overriding signals.

The effects of such relative motion and external reflections can be substantially reduced by providing a mounting for the microwave unit which is close to and fixed in position relative to the subject. Actual contact, secure but non-oppressive, is the best way to obtain this relationship. In this second arrangement there is virtually no relative surface motion since the microwave unit moves with the surface, and leakage is reduced to the extent that the

(1) J.S. Gravenstein, et al, "Essential Noninvasive Monitoring in Anesthesia," Grune and Stratton, New York, 1980, Section I, Chapter 2, p 27.

microwave antenna structure can be made to conform to the subject's head, chest, or wrist. Actual observations have shown that the strong signal from the dominant respiration-induced body motion is greatly suppressed when direct contact monitoring is employed. As a side comment, it has also been observed that when this contact is obtained by either the subject or a second individual holding the microwave monitor in place against the chest or head, there is considerable motion resulting from involuntary muscle movement. A secure wrap-around or strap type of securing appears to be necessary to minimize external motion artifacts.

The selection of frequency is more important in this contacting arrangement because some degree of penetration is required. Higher frequencies penetrate less deeply because of absorption losses. An example of the penetration vs frequency is given by Johnson and Guy.(2) The average penetration of high water content tissue by microwave signals at 10 GHz is 3.4 mm while the distance is increased to 17 mm at the lower frequency of 2.45 GHz. The phase sensitivity at the lower frequencies is increased because the velocity of propagation through the tissue is reduced and the effective wavelength becomes shorter. Thus, small arterial displacements produce significant phase changes. The earlier example at 2.45 GHz showing a two way phase change of only 0.6^{0} in air from a surface motion of 0.1 mm would be increased to over 4^{0} in a medium having a dielectric constant of 47, which is a typical value for human tissue of high water content.

The longer-range purpose of this program is to develop a sensor for monitoring the superficial temporal artery which may be mounted in a flight helmet. In this application, the fixed-position contacting arrangement will be

(2) Johnson and Guy, "Biological Effects of Electromagnetic Waves," Proceedings of the IEEE, June, 1972, p 694.

relatively simple to implement and was selected as the design approach. Test units operating at both 10.52 and 2.45 GHz were assembled and tested. Both functioned but the higher frequency unit, which had a smaller antenna structure, appeared to be more position dependent and subject to external interference to a greater degree than the larger 2.45 GHz module. Although somewhat larger in cross-section than our objective 2.0" x 2.0", the operating frequency of 2.45 GHz was selected for the deliverable model. This frequency is one of a small number set aside by the Federal Communication Commission for industrial, security, and medical applications such as microwave heating.

MODULE DESIGN

The mechanism by which an unmodulated cw (continuous-wave) microwave radar can detect motion is essentially a wave interference phenomenon which can be analyzed from several viewpoints. Commonly used is the Doppler shift analysis in which the velocity difference between transmitter and reflector effectively adds to or subtracts from the velocity of propagation of the radio wave producing an offset "Doppler frequency" (fd) from which the relative velocity frequency (Vr) can be determined:

$$Vr = (fd.c)/(2f_T)$$

where c = velocity of propagation (3×10^8 m/s)

and f_T = frequency of transmitted signal

This analysis is particularly applicable to the measurement of nominally continuous motion such as in speed sensors for traffic radars. Although the equation is valid for any motion, sporadic or alternating motions do not lead to simple analysis in the frequency domain and "Doppler frequency" is not particularly meaningful.

The same basic phase displacement mechanism is also manifested in the use or measurement of transmission lines in which forward (transmitted) and backward (reflected) components of the same microwave signal produce an interference pattern of standing waves whose relative amplitude and phase are determined by the distance to one or more reflection-producing mismatch points or components. By employing a microwave circuit consisting of a directional coupler to take a sample of the transmitted signal, a circulator to separate the reflected signal from the transmitted signal, and a mixer to combine them in a controlled manner, an output signal generally indicative of the phase relationship can be obtained. If the reflecting element is positioned such that a maximum mixer voltage is obtained from an in-phase condition, movement of the element by a two-way distance of one-half wavelength to an out-of-phase condition will result in a minimum mixer voltage. A probe monitoring the standing wave will evidence the same effect. Variation in the mixer output or the probe voltage will be indicative of relative motion. It is this mixer technique which is commonly employed to sense motion, regular or sporadic. The first units evaluated for the superficial temporal artery used this conventional approach which is shown in Figure 1a.

The transmitter source was a small microwave oscillator module manufactured by NEC for various applications. It consists of an X-band GaAs (gallium arsenide) FET (field effect transistor) device configured as an oscillator with a dielectric resonator (DRO) in the feedback loop for frequency stabilization. A small commercial ferrite circulator with connectors removed was mounted on a 1.8" x 1.6" x .032" thick low-loss glass-reinforced PTFE (polytetrafluorethylene) circuit board on which 50-ohm transmission lines were etched for matching and interconnection (Fig. 1b). One line connected the FET-DRO to the circulator input; another connected the circulator output to a Schottky-barrier

diode mixer. The common arm of the circulator was connected to a microstrip patch antenna designed for 10.52 GHz operation. The impedance characteristic of this antenna is shown in Fig. 2. A PTFE dielectric block of the same size as the antenna patch and as thick as the circulator body was attached over the antenna to better concentrate the output power. The mismatch at the common arm was more than sufficient to provide local oscillator drive to the single-ended mixer eliminating the need for a directional coupler.

This conventional cw radar breadboard module was placed against the side of the head essentially as shown in Fig. 3 with the PTFE block generally positioned over various locations of the superficial temporal artery. A fully detectable signal, of the type shown in the osciloscope photograph of Fig. 4 was obtained after amplification in a circuit using a CA3078A micropower operational amplifier adapted from a previous heart-rate monitor program. Although distinct pulse signals were visible, the microwave structure did not appear to lend itself to compact packaging without a considerable effort at miniaturization.

Effort was then directed towards an approach based on a third viewpoint of the basic phase-relationship mechanism by which motion can be detected. The effect can also be considered in terms of the reflection characteristics of the load - a technique widely used for measurement of impedance characteristics of microwave components. The load may be fully defined in terms of the phase and magnitude of the reflected signal which can be separated from the transmitted signal by directional couplers. Since a positional change of the load, in this case the reflecting surface, will produce at least a phase change in the reflection coefficient, motion can be sensed and defined as a change in load impedance. It is known that any microwave oscillator connected to a load, either directly or via an antenna, will be affected to some extent by changes in that load depending upon the degree of coupling and isolation.

The oscillator frequency will be "pulled" and the operating current will be perturbed some small amount as the load changes. It is possible, therefore, to sense the existence of motion by observing current variations in the oscillator while all other variables are held as constant as possible.

To ascertain the feasibility of using this approach, the circuit shown in Fig. 5 was constructed and tested. Finger motion about 2 inches from the antenna was observed to produce a voltage output of approximately 0.5 V pk-pk from the CA3001 amplifier. Several other circuit variations were tested. One test was made with the patch antenna contained within a dielectric bounded metal shield (Fig. 6), and a version with the FET-DRO coupled directly into a 1" x 1/2" rectangular waveguide section was built and tested (Fig. 7).

Although all three variations could be positioned so as to generate a viewable pulse on the oscilloscope, the presence of extraneous motion signals seemed to predominate. It was decided that deeper penetration might be desirable and o more testing was done at 10.52 GHz. Instead, a bipolar transistor oscillator based on a design suggested by Hewlett-Packard for the HXTR-4101 was built and tuned for use at 2.45 GHz which is another FCC-approved industrial frequency allocation. The simpler current sensing approach was chosen with the emitter resistor selected as the signal generating impedance. A large emitter resistance should serve to stabilize the oscillator current against power supply variations. A Burr-Brown INA104CM instrumentation amplifier integrated circuit was used to amplify the weak signal to a level conveniently viewable on a conventional oscilloscope. A larger microstrip patch antenna was used to try to lessen the positional dependency of the monitor with good results.

The basic circuit is shown by the schematic diagram of Fig. 8. Reasonably good performance was obtained with this circuit and, with the addition of some

extra filter chokes and capacitors to reduce stray rf leakage, it was used in the deliverable model.

DESCRIPTION OF DELIVERED MONITOR

The deliverable superficial temporal artery (STA) monitor was assembled using the aforementioned design approach and circuit arrangement. Since leakage is a major concern because extraneous motions complicate viewing this pulse waveform, the monitor was assembled with three levels of shielding as shown in the sketch of Fig. 9. The redesigned antenna was one of the two types used on the U.S. Army Heart Rate Monitor program.(3) It is a 1.9" x 1.6" microstrip patch radiator on a .062" thick glass-reinforced PTFE circuit board with a dielectric constant of 2.3. It is known to be well matched when held against the body through a layer or two of clothing. The oscillator, which is mounted on the antenna backplane, is built on a higher dielectric substrate (approximately 10) and is under 1" x 1" x 0.15" in size. The instrumentation amplifier is also mounted on the antenna circuit board backplane as a separate circuit. The overall assembly slides into a PTFE housing of 2.5" x 2.5" x 0.8" external dimensions with the antenna face down against the 0.10" thick insulating face. Photographs of various assembly stages and views are shown as Figs. 10, 11, and 12. The final metal shield slides over the PTFE housing leaving only the antenna face unshielded. It is this face which is held against the superficial temporal artery to detect motion. Separate power and signal cables were brought out from the module using standard connectors.

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(3) Contract No. DAMD 17-83-C-3018, U.S. Army Medical Research and Development Command, Ft. Detrick, Frederick, MD.

PERFORMANCE EVALUATION

The performance evaluation consisted of operating the STA monitor at various positions against the side of the head of a volunteer subject and observing the output waveforms on an oscilloscope. A Tektroni· 564 storage oscilloscope set to a sweep rate of one trace every 5 or 10 seconds was used for real-time viewing of the output signal. A digitizing oscilloscope (HP52000A) was used for storing the waveforms obtained at several specific positions over the superficial temporal artery. Photographs were taken of the digitizing oscilloscope display. The "dotted" character of this display is a consequence of the digital sampling rate of the oscilloscope. The sweep rates and vertical sensitivities are shown on the individual photographs, and the pulse rates and output signal amplitudes may be determined from these calibrating factors. Figures 13 through 16 show these oscilloscope phoptographs along with an associated indication of the approximate position of the STA monitor for that particu¯ar waveform. In each case, the STA monitor was held in place by a tight elastic headband. The subject tried to limit any head movement or muscular activity such as talking, chewing, or facial flexation during the sweep time. No attempt was made, however, to suppress the normal respiration of the seated subject.

No detailed analysis of the specific character of the signal waveform will be attempted. The amplitude of the signal is believed to be generally an integrated function of the magnitude and area of motion to the extent that the rate of motion produces signal components within the bandpass of the instrumentation amplifier circuit. The arterial pulse action is distinctly discernible, and pulse rate can be readily determined from the calibrated time scale. In the presented four examples, there are between 10 and 11 major signal excursions during the 10 second sweep time. This represents a pulse rate of 60

to 66 beats per minute which was verified by palpation of the radial artery.

Between the major excursions representing the pulse action, there is considerable signal structure which may represent elements of the overall cardiac cycle - the PQRST complex. These have been observed more distinctly when using the STA monitor against the upper chest, but any such analysis is beyond the scope of this program and the expertise of the project personnel.

In the oscilloscope photograph of the waveform obtained when the STA monitor was above the ear (Fig. 15), an extraneous signal can be observed between the fifth and sixth pulses. This was probably caused by some small muscular action in the head which flexed the headband and produced a short burst of relative motion. When the STA monitor was positioned such that one-half was over the ear, extraneous background signals were more significant. This was probably the result of external relative motions because of the microwave leakage from the air-gaps resulting from such a non-conformal positioning. *Conversely, the least extraneous signal seemed to be produced* when the STA monitor was positioned forward of the ear where the flat antenna face would be in substantially close contact with the relatively flat side of the subject's head and leakage from air-gaps would be minimized.

The STA was further evaluated during a performance demonstration at Wright-Patterson AFB on January 23, 1986. In general, the same type of waveforms were observed. Air Force personnel recorded some typical waveforms, commented on the artifacts generated by specific facial muscle motions, and offered suggestions about conformally shaping and positioning the STA monitor to lessen such artifacts.

CONCLUSIONS

1. The delivered STA monitor demonstrated the feasibility of obtaining, in a non-invasive manner, distinct waveforms representing the pulse action of the superficial temporal artery at various positions on the side of the head.

2. Smaller versions of the STA monitor can be designed and built in a configuration suitable for installation in a flight helmet.

3. The major limitation to the practical use of the STA monitor in centrifuge testing or actual flight applications is the presence of extraneous signals which result from internal muscular artifacts or external motions sensed by microwave signal leakage.

4. Redesign of a more conformal STA monitor with a smaller antenna and improved shielding should greatly reduce these limiting conditions.

RECOMMENDATIONS

The following list of recommendations is submitted to suggest both improvements which could be made to the STA monitor and other physiological and non-physiological applications for microwave monitoring.

A. Improvements to STA Monitor

1. Redesign the existing STA monitor into a reduced size housing with a smaller antenna for optimized positioning. The overall size of an improved microwave module is estimated at approximately 25 mm x 25 mm x 6mm thick (1" x 1" x 0.25"). The instrumentation amplifier would be built into the interconnect cable so as to be remote from the helmet but local to the subject. Shielding would be improved by the addition of EMI suppressing material along the contact edges of the monitor.

2. Fabricate a small number of such reduced size STA monitors to permit separate monitoring of different sites in order to analyze the possibility of comparative signal processing to isolate the pulse from unwanted artifacts.

3. Fabricate a conformal STA monitor with dual pickups to view the area of the occipital branch where less muscle artifacts are expected to be present. Such an arrangement may be especially pertinent to flight helmet installation.

B. Other Physiological Monitoring

1. Design and fabricate a probe type monitor which would detect cardiac or arterial pulse motion on contact or through protective clothing for rapid diagnosis of mortality. The probe would provide an LED or LCD flashing light in sequence with the pulse. Rate could be determined from normal counting of such light flashes.

2. An improved and reduced weight and size version of the Heart-Rate Monitor developed for the U.S. Army could be designed and fabricated in prototype quantities. In addition to the LED/LCD flash for each pulse, an accurate display of beats per minute would be included.

3. Small arterial pulse monitors could be designed and fabricated which would be suitable for positioning over other pulse points. Locating such monitors over the various arteries may provide means for sensing physiological effects related to magnitude or timing differences among these pulses.

4. Non-invasive monitors could be designed to detect internal motions other than those which are pulse related. Respiration monitors are certainly feasible. It may be possible that motions related to blood flow or muscular actions such as reflexes or cramps could be studied.

5. The possibility of designing and fabricating vital signs monitors in ambulance litters, operating tables, or hospital beds is considered feasible. Monitoring of the patient lying on such a "mattress" would eliminate the need for attachment of sensors and would be completely non-obstructive to medical personnel which would be especially advantageous during emergency treatment or surgery.

6. Sensors indicating muscle action (flexing of a muscle, change in pressure of a pilot's grip on the control stick) could be developed, based on preliminary experiments performed with existing sensors.

C. Non-Physiological Monitoring with Microwaves

1. Microwave "tags" are essentially reflectors which can be coded so as to provide an identifiable return from a specific point or object. Use of such a tag allows the sensing of motion or location of one specific individual or object from amidst many other reflection generating objects. When combined with other medical or non-medical sensors, the problems of separating one from many signals is substantially reduced. Remote non-invasive monitoring may be practical in certain cases.

2. Microwave sensors provide an excellent means of measuring speed and distance in environments where contact or visibility problems exist. Many problems involving measurement of these parameters under difficult conditions, such as the underside of locomotives or inside of blast furnaces, have been successfully solved with microwave sensors, some simple and inexpensive and others of a specialized and costly nature.

3. A monitor providing information on the displacement of a part of the body (e.g. slumping of a pilot's head during blackout) would be implemented by detecting a change in the "tagged" position of the monitored site.

APPENDIX A

TASK STATEMENT FROM SYSTEMS RESEARCH LABORATORIES

(Attached to P.O. No. 44277)

TASK STATEMENT

DEVICE FOR THE DETECTION OF THE SUPERFICIAL TEMPORAL ARTERY PULSE IN HUMAN SUBJECTS EXPOSED TO HIGH ONSET RATE HIGH SUSTAINED +GZ ACCELERATION STRESS

Background:

The acceleration onset rates developed by current first-line fighter aircraft, such as the F-16, pose unique physiological hazards to the military aviator. This level of performance leads to episodes of abrupt loss of consciousness with no antecedent symptoms. It would be desirable to have a non-invasive device sufficiently small to be built into the aircrew helmet, and that would be capable of detecting the presence or absence of the pulse wave in the superficial temporal artery (STA).

The STA is chosen since it is easily accessible for such instruments as the *Doppler Ultrasonic flowmeter and a variety of visible and infra-red devices* sensitive to changes in the optical characteristics of hemoglobin or other blood components/characteristics. Extensive laboratory experience with techniques such as the Doppler and infra-red devices have shown that they are useful but not applicable to the cockpit environment because of their sensitivity to vibration, narrow beamwidth, and precise positioning requirements.

Recent advances in gigahertz wavelength radar technology have resulted in techniques that may permit detection of the STA pulse (see Nowogrodzki, et al, Attach. 1). This technology has been developed to a sufficient degree to permit, for example, the detection of heart and lung motion from a distance of about 2 meters (Attach. 1). It is postulated that a device of this type could be incorporated in a flight helmet, utilizing a patch antenna and a telemetry module to detect and transmit pulsatile events to a system capable of decision

making with respect to the likelihood of acceleration induced loss of consciousness. This is based upon the physiologic consideration that loss of pulsatile flow in the STA is a precursor to blackout (loss of perfusion to the retinal artery) and subsequent loss of consciousness given continued stress.

Scope:

This effort is to make use of a modified, experimental RCA type S587 milliwatt continuous wave 10.6 GHz device, or some similar device, to develop a system that can be worn by volunteer human centrifuge subjects. It has been determined by consultation with the Radiation Sciences Division at the USAF School of Aerospace Medicine, Brooks AFB, TX that radiation at this frequency and power level is not hazardous.

The device is to be fabricated in such a manner so as to be easily fitted to the subject in a manner that will limit the motion of the antenna to the required degree under the inertial effects of high sustained headward acceleration at up to nine times Earth gravity (+9 Gz).

Signal conditioning and transmission circuits are to be provided as a part of the device so that the pulse analog signal can be transmitted over sliprings to the Medical Monitoring Station of the AFAMRL Dynamic Environment Simulator. Transmission of the signal locally (within the gondola of the centrifuge) may be via hardwire or telemetry whichever is deemed to be most suitable. If the experimental device can be designed to provide a +/-5 volt signal going into the sliprings, such a device should be completely compatible with the centrifuge installation.

Means are desired within the signal conditioning circuitry to allow extraction of the pulsatile signal from a potentially noisy background. It is anticipated that a patch antenna with dimensions of 2 inches x 2 inches would be

of sufficient size to permit some latitude in positioning of the device over the STA.

Schedule:

This development effort is estimated to require a period of approximately six months after commencement.

APPENDIX B

RCA PROPOSAL TO

SYSTEMS RESEARCH LABORATORY

Proposal

In response to the Systems Research Laboratories, Inc., request dated March 29, 1985, RCA Laboratories proposes to perform the following tasks:

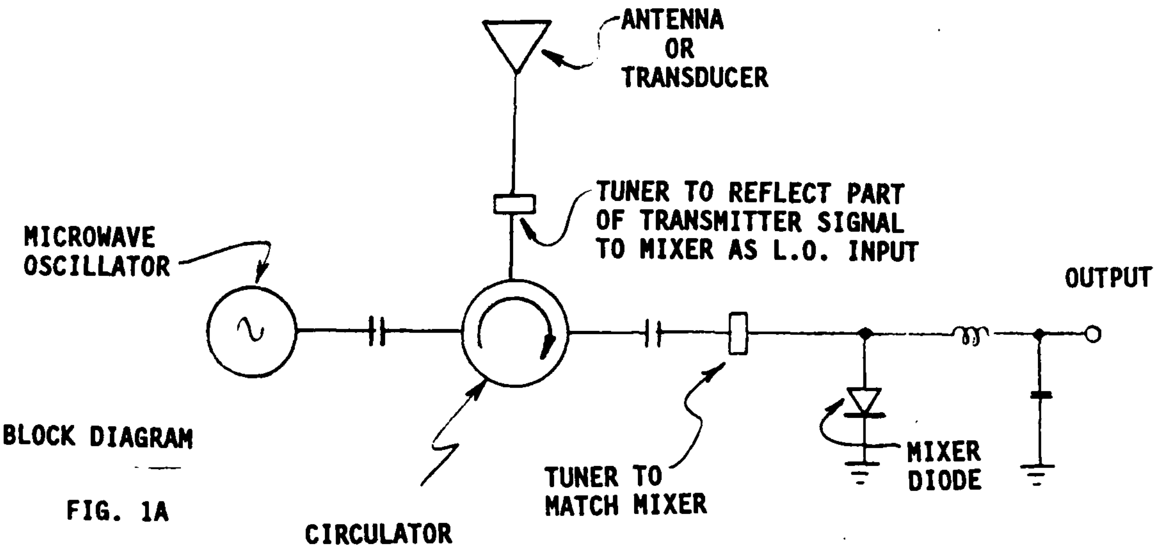
(1) Modify an existing experimental RCA monitor so that it may detect the presence or absence of pulses in the superficial temporal artery of a human subject;

(2) Develop an antenna of sufficiently small size and of a geometry suitable for attachment to the head of a subject undergoing tests in a high-acceleration environment;

(3) Provide, at a location remote from the antenna, a compact circuit and power-supply module connected to the antenna by means of a flexible coaxial cable and having available an analog output signal characteristic of the superficial temporal artery pulses and suitable for display on an oscilloscope;

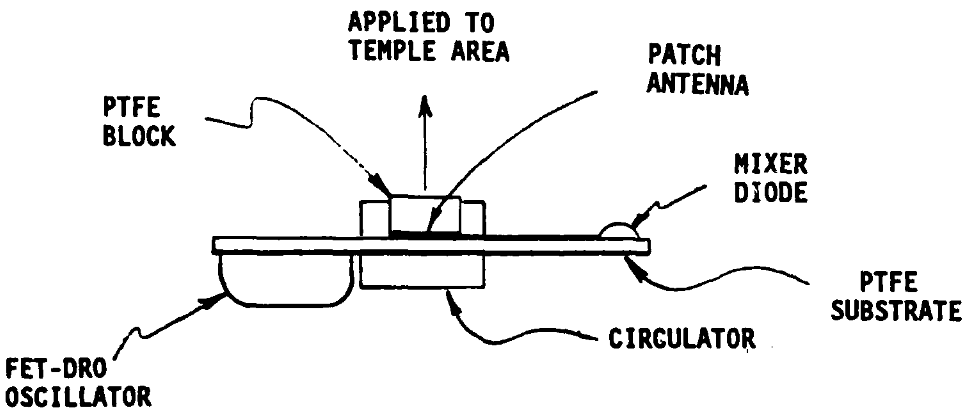
(4) Assist Systems Research Laboratories engineers in the initial installation and operation of the unit.

These tasks will be performed by personnel of the RCA Laboratories' Microwave Technology Center. It is anticipated that the design of the experimental monitor will be such that, if desired, it could be incorporated at some future time in a more sophisticated unit built into a subject's flight helmet.



BLOCK DIAGRAM

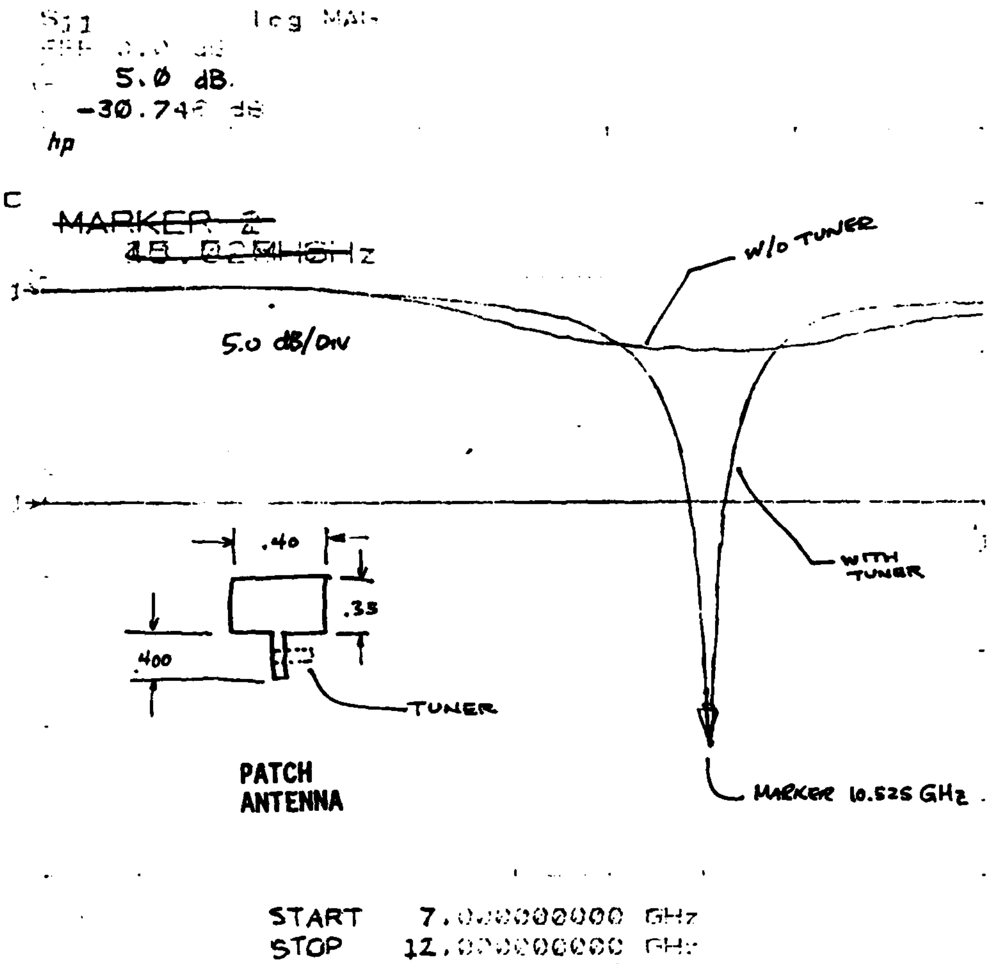
FIG. 1A



BREADBOARD CONFIGURATION

FIG. 1B

CONVENTIONAL SIMPLIFIED MICROWAVE
MOTION DETECTOR



ANTENNA IMPEDANCE CHARACTERISTIC

FIG. 2

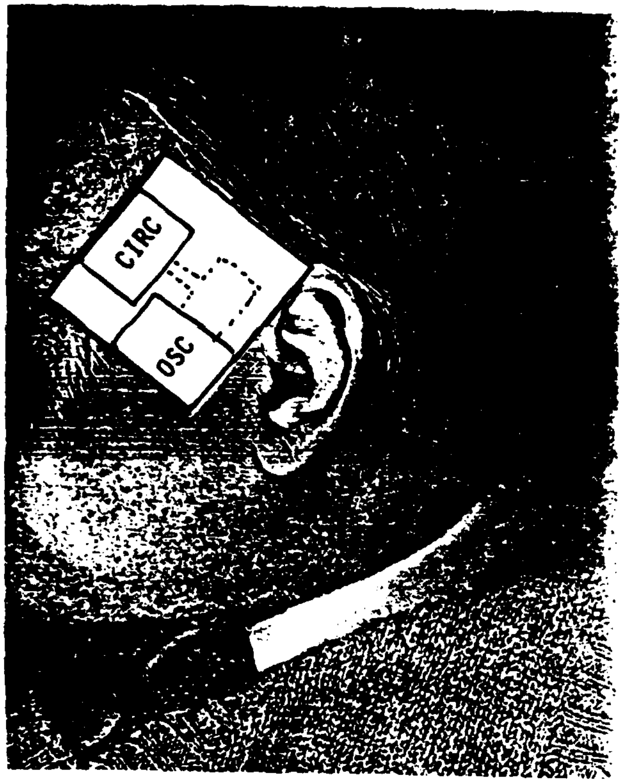
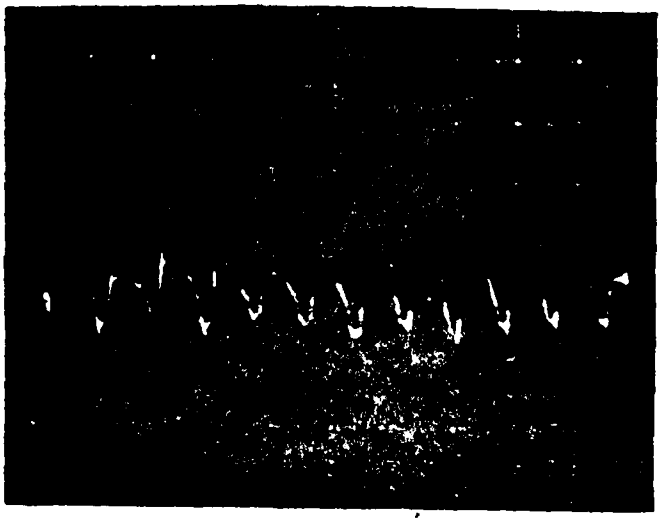


FIG. 3

PLACEMENT OF BREADBOARD
CONVENTIONAL MICROWAVE MOTION DETECTOR

OUTPUT WAVEFORM FROM BREADBOARD
CONVENTIONAL MICROWAVE MOTION DETECTOR



AC COUPLED
.01V/DIV

1.0 SEC/DIV
APPROXIMATE

FIG. 4

MIXER OUTPUT WITH X100 GAIN

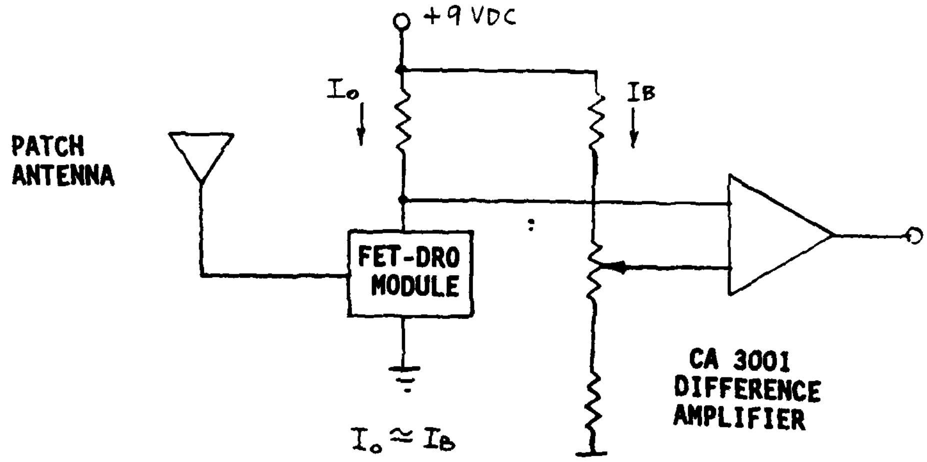


FIG. 5

OSCILLATOR CURRENT CHANGE MOTION DETECTOR

DIELECTRIC BOUNDED
METAL SHIELDED
PATCH ANTENNA CONFIGURATION

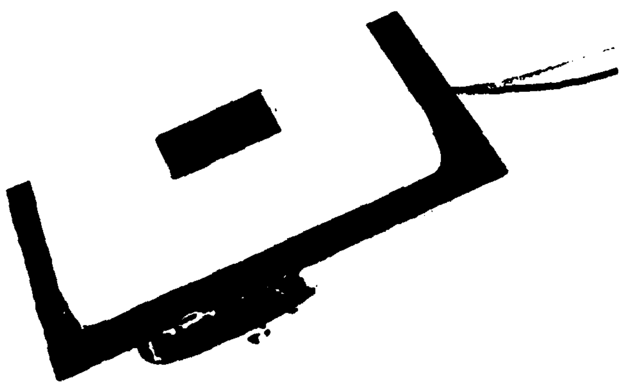
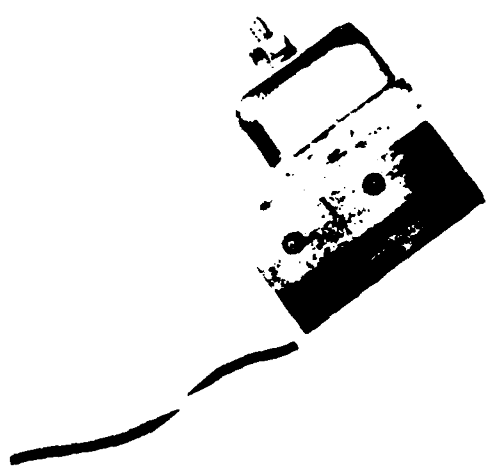
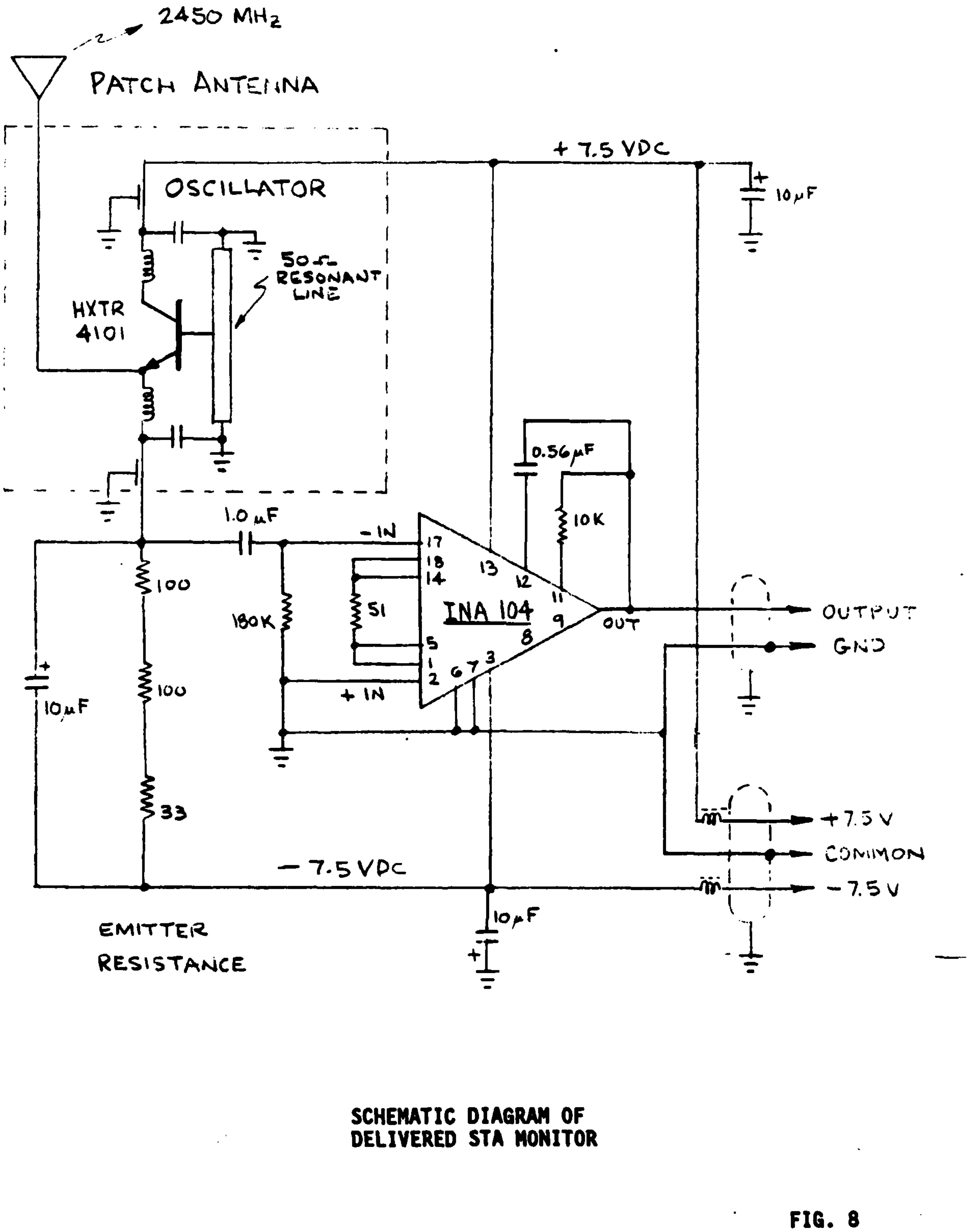


FIG. 6



WAVEGUIDE COUPLED
FET-DRO CONFIGURATION

FIG. 7



SCHEMATIC DIAGRAM OF
DELIVERED STA MONITOR

FIG. 8

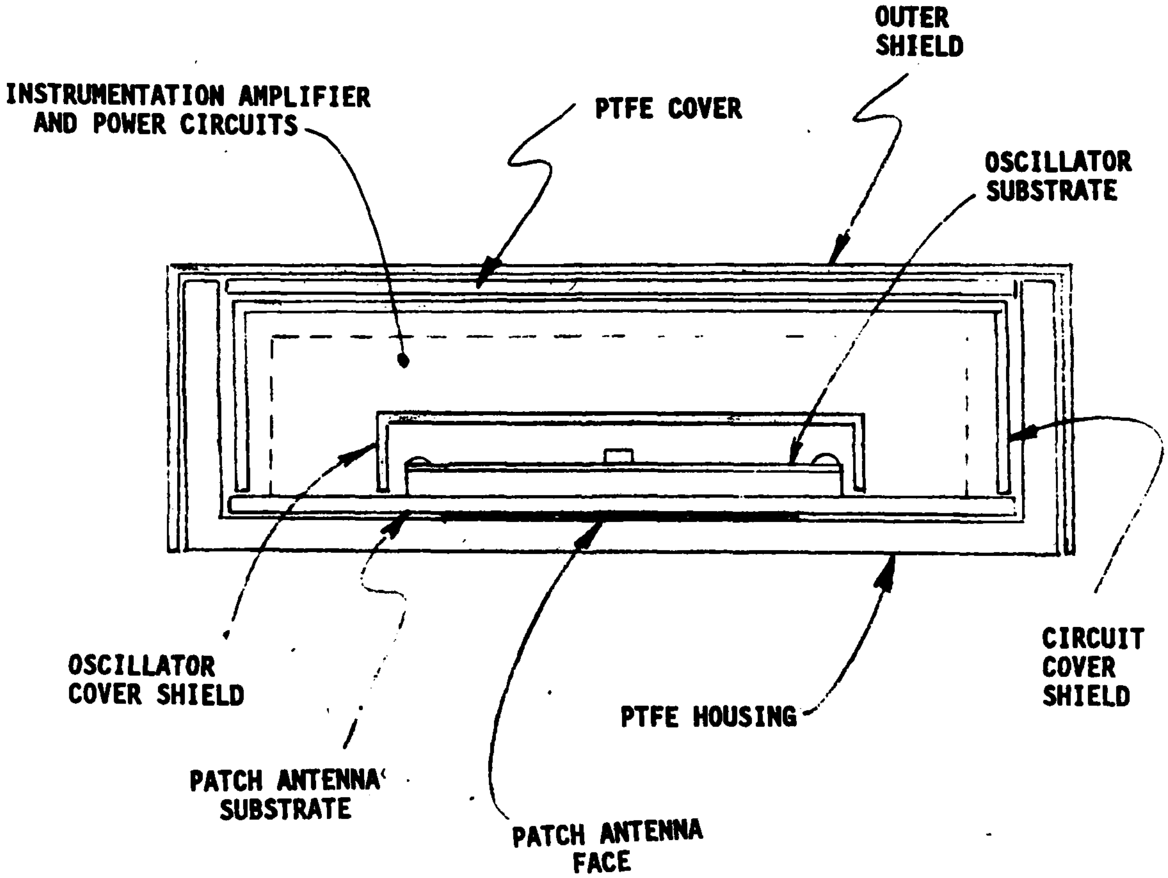
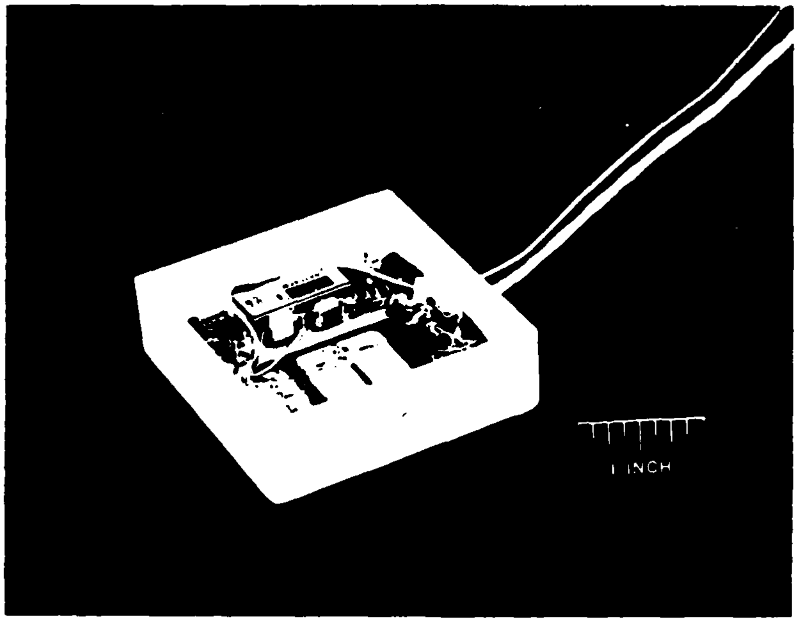


FIG. 9

FABRICATION DIAGRAM OF STA MONITOR
SHOWING POSITIONS OF SHIELDING COVERS

NO SHIELD COVERS
IN PLACE

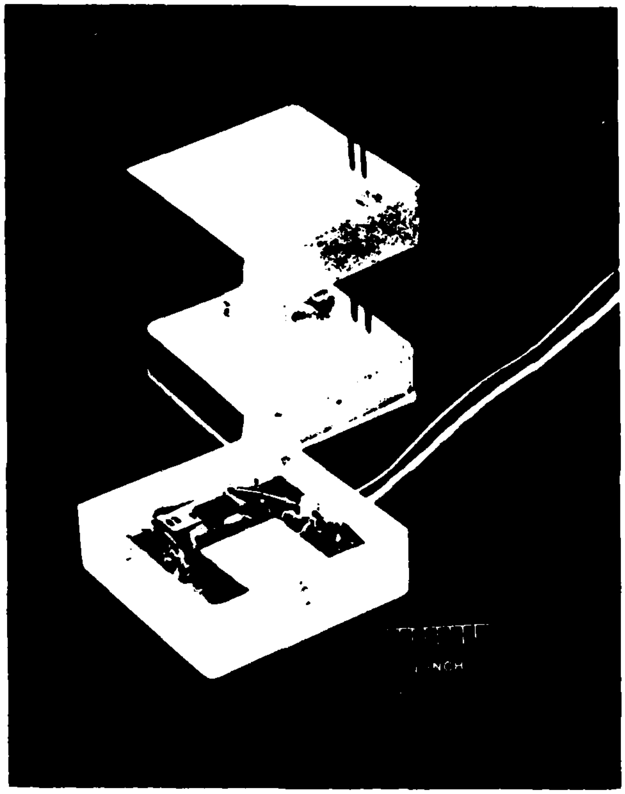


PHOTOGRAPH OF
STA MONITOR OSCILLATOR

FIG. 10

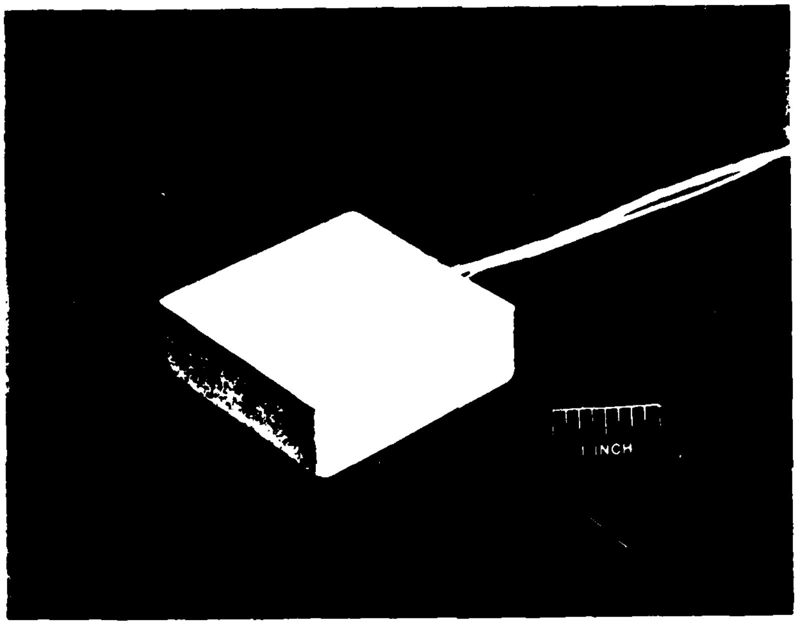
OSCILLATOR
COVER IN PLACE

OTHER SHIELDS SHOWN IN
INVERTED POSITION



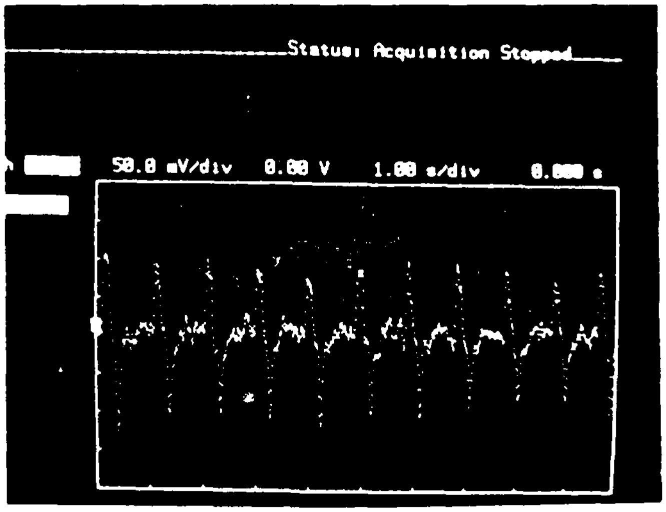
PHOTOGRAPH OF STA MONITOR AMPLIFIER CIRCUIT

FIG. 11



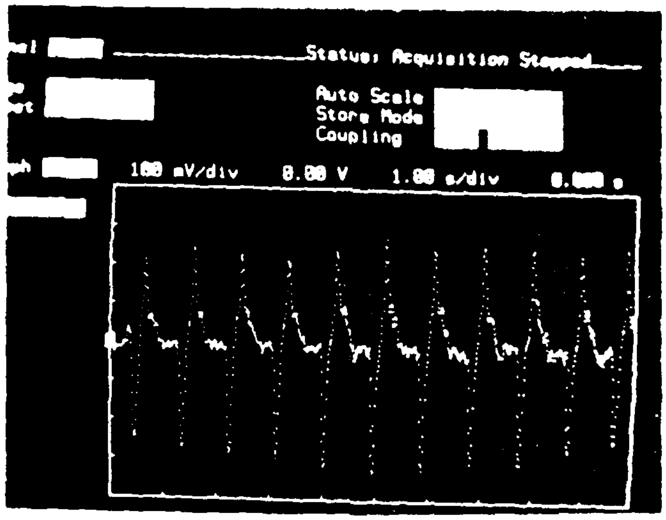
PHOTOGRAPH OF ASSEMBLED STA MONITOR

FIG. 12



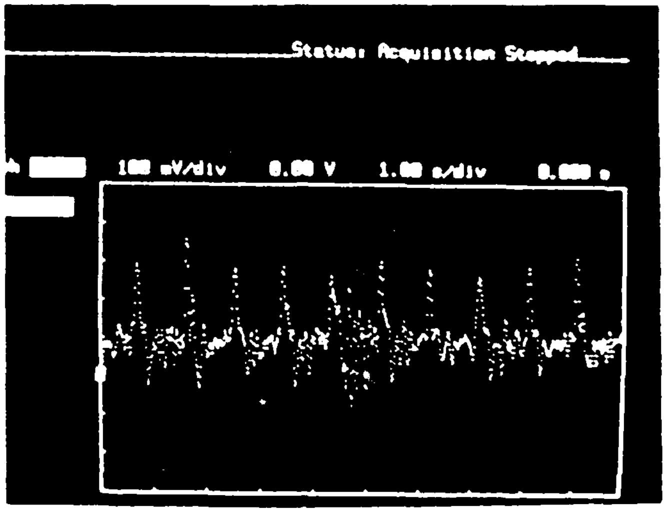
WAVEFORM WITH STA MONITOR
POSITIONED OVER TEMPLE AREA

FIG. 13



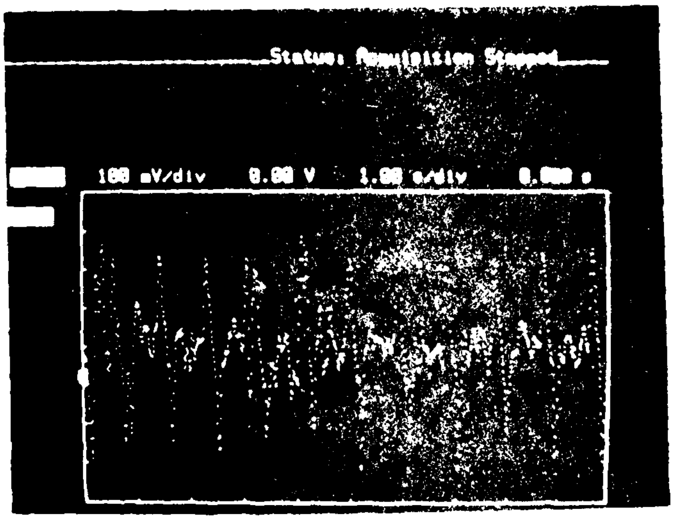
WAVEFORM WITH STA MONITOR
POSITIONED IN FRONT OF EAR

FIG. 14



WAVEFORM WITH STA MONITOR
POSITIONED ABOVE EAR

FIG. 15



WAVEFORM WITH STA MONITOR
POSITIONED HALF OVER EAR

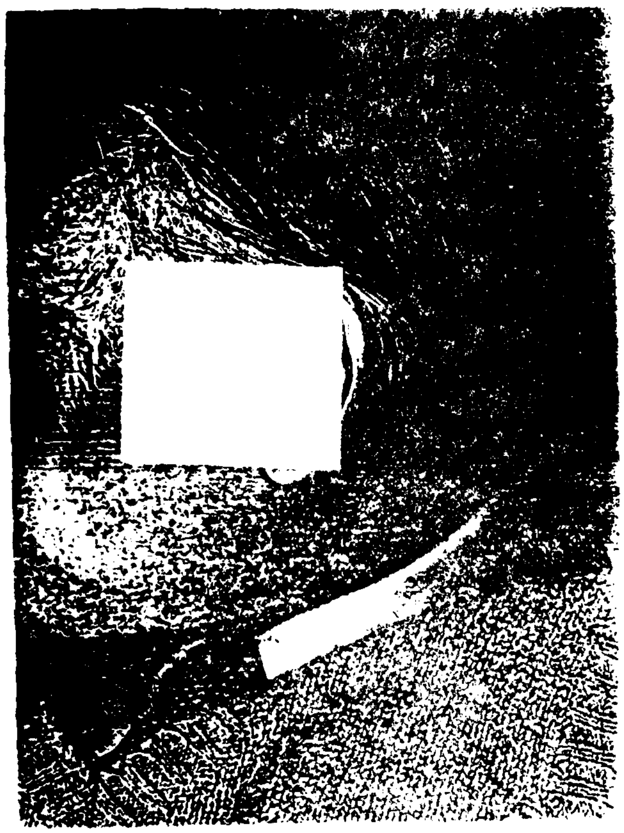


FIG. 16